10. GEOTECHNICAL EXPLORATION PROGRAM

Geotechnical site investigations should be conducted in multiple phases to obtain data for use during the planning and design of the tunnel system. Geotechnical investigations typically are performed in two or three phases during the preliminary and design stages. Geotechnical investigations provide the required data for finalizing the tunnel alignment, evaluating construction methods and developing an accurate opinion of probable construction costs. The geotechnical data obtained during the investigations also should provide a basis to:

- Identify potential geologic hazards
- Determine ground conditions
- Characterize soil and rock mass
- Establish baseline conditions along the tunnel alignment

The total cost for all phases of the geotechnical exploration program for the Fall Creek/White River Tunnel project can be anticipated to be 1 to 2 percent of the total project construction cost.

10.1 PHASE 1

The initial phase of the geotechnical exploration program should be conducted during a planning or feasibility stage in order to obtain data that provides a better understanding of the existing ground conditions and characteristics. Although multiple data gaps exist to completely design the tunnel, the Phase 1 geotechnical exploration program scope should focus on planning level answers. Phase 1 is critical for providing an understanding of the subsurface materials in order to determine the appropriate construction methodologies, identify the risks that require mitigation and initiate development of opinion of probable construction costs. The work performed during the Phase 1 geotechnical exploration program should focus on the following aspects:

- Depth to the bedrock surface
- Soil and rock mass engineering characteristics

10. GEOTECHNICAL EXPLORATION PROGRAM

- Presence of obstructions in the soil
- Extent and properties of clay layers in the overburden
- Stratigraphic profile along the alignment
- Extent of karst development in the bedrock
- Hydrogeologic properties of the soil and rock

The hydrogeologic properties of the rock should be tested in distinct intervals to allow the tunnel to be placed in rock with lower permeability, if present. Locating the tunnel in rock with lower permeability would help minimize the amount of groundwater inflows during tunnel construction and exfiltration during tunnel operation, as well as reduce the requirements and cost for pre-excavation grouting.

During the Phase 1 geotechnical exploration program, it is recommended that borings be drilled at:

- All potential shaft locations along the alignment
- Locations where shafts are greater than 5,000 feet apart

With these scope and drilling recommendations, all data obtained during the Phase 1 geotechnical exploration program should retain its value if the tunnel route is revised slightly or an alternative shaft location is required. Additional borings and testing would be done during Phases 2 and 3, if necessary, to fill the data gaps to complete the design.

As shown on Figure 10.1, there are 26 borings recommended to be drilled along the tunnel alignment. This boring program assumes that the West Alignment for the main tunnel, the Bluff Road working shaft, and the Sutherland Avenue retrieval shaft are selected. The Phase 1 geotechnical exploration program can be separated into two parts, Phase 1-A and Phase 1-B, to accommodate funding. Phase 1-A would consist of up to 10 borings located at the working, intermediate working, retrieval and selected drop shafts, and at two locations along the tunnel route. These borings will provide a representation of the subsurface conditions across the entire alignment and

10. GEOTECHNICAL EXPLORATION PROGRAM

REMOVE SHEET AND REPLACE WITH FIGURE 10.1

10. GEOTECHNICAL EXPLORATION PROGRAM

at the most critical shaft locations. The locations, depths and testing of the remaining borings to be drilled in Phase 1-B can be adjusted based on the findings from the Phase 1-A boring program.

Twenty-four of the 26 borings are located at or adjacent to shaft locations. These holes should be advanced vertically to allow soil and rock sampling and testing. Piezometers are proposed to be installed in all 26 boreholes to determine the groundwater conditions before, during and after construction. To establish bedrock conditions and identify any irregularities, 21 of these borings should be drilled an additional 100 feet or three tunnel diameters below the proposed tunnel invert elevation. Therefore, these boreholes are expected to extend 350 feet below the existing ground surface. To vertically locate the tunnel, these 21 boreholes also should be utilized to identify zones of low permeability rock. The three remaining shaft borings should be located in the overburden adjacent to a deep boring/piezometer installation, known as nested well. With this nested well configuration, an evaluation of how the overburden and bedrock are hydraulically connected at the working, intermediate working and retrieval shaft locations can be performed to evaluate the appropriate shaft construction techniques.

At a minimum, two borings located along the tunnel alignment should be drilled at a 15 degree angle from vertical in an attempt to intersect the near vertical jointing in the rock where solution activity may be most prevalent. Table 10.1 summarizes the Phase 1 boring program.

10. GEOTECHNICAL EXPLORATION PROGRAM

Table 10.1
Phase 1 Boring Schedule

Boring	Phase	Location	Depth	Orientation	Media Sampled
B-1A	1A	Bluff Road Shaft	350 ft	Vertical	Soil & Rock
B-1B	1B	Bluff Road Shaft	50 ft	Vertical	NA [1]
B-2	1B	DS-01	350 ft	Vertical	Soil & Rock
B-3	1A	DS-02	350 ft	Vertical	Soil & Rock
B-4	1A	DS-03	350 ft	Vertical	Soil & Rock
B-5	1A	Hwy 40 on tunnel route	375 ft	15° from vertical	Rock
B-6	1A	DS-04	350 ft	Vertical	Soil & Rock
B-7	1B	DS-05	350 ft	Vertical	Soil & Rock
B-8	1B	DS-06	350 ft	Vertical	Soil & Rock
B-9	1B	DS-07	350 ft	Vertical	Soil & Rock
B-10A	1A	DS-08	350 ft	Vertical	Soil & Rock
B-10B	1B	DS-08	50 ft	Vertical	NA [1]
B-11	1B	DS-09	350 ft	Vertical	Soil & Rock
B-12	1B	DS-10	350 ft	Vertical	Soil & Rock
B-13	1A	Milburn St on tunnel route	375 ft	15° from vertical	Rock
B-14	1B	DS-11	350 ft	Vertical	Soil & Rock
B-15	1A	DS-12	350 ft	Vertical	Soil & Rock
B-16	1B	DS-13	350 ft	Vertical	Soil & Rock
B-17	1A	DS-14	350 ft	Vertical	Soil & Rock
B-18	1B	DS-15	350 ft	Vertical	Soil & Rock
B-19	1B	DS-16	350 ft	Vertical	Soil & Rock
B-20	1A	Sutherland Ave Shaft	350 ft	Vertical	Soil & Rock
B-20A	1B	Sutherland Ave Shaft	50 ft	Vertical	NA [1]
B-21	1B	DS-19	~100 ft [2]	Vertical	Soil & Rock
B-22	1B	DS-20	~100 ft [2]	Vertical	Soil & Rock
B-23	1B	DS-21	350 ft	Vertical	Soil & Rock

[1] Borings should be drilled with no soil samples collected (i.e., drilled blind).
[2] Borings should be drilled to top of rock.

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If possible, the borings should be located a minimum of 15 feet from the anticipated tunnel alignment so the boring is not encountered during mining. It is anticipated that the borings will be advanced through the overburden to bedrock by rotary wash methods using water and bentonite or polymers to maintain an open hole. The borings would be cased to rock while the drilling fluid is flushed from the hole before initiating rock coring. All borings drilled into rock at or near the shaft locations should be sampled throughout the overburden and rock. The two inclined and three nested well borings should be drilled blind in the overburden without soil sampling. Rock coring and water pressure testing of the rock should be conducted in the inclined borings.

The recommended Phase 1 geotechnical exploration program includes overburden sampling using split barrels with standard penetration tests in granular soils and thin-walled tubes in cohesive soils. Rock, soil and groundwater samples also should be collected for physical and chemical analysis. Groundwater level and condition should be monitored from the piezometers installed in each borehole. Coring of bedrock should be required to perform water pressure tests to determine permeability by using a dual (straddle) packer assembly in stages throughout the full depth of rock in each boring. Additionally, downhole video logging should be performed to observe the orientation, size, and characteristics of discontinuities in the rock.

During the field investigation, an experienced geologist or geotechnical engineer should be on site to keep a descriptive geotechnical log of each boring. Drilling observations and explosive gas monitoring results should be included in the drilling records.

The following testing should be performed:

- Index and strength testing
- Grain size analysis and Atterberg limits
- Consolidation of cohesive soils
- Moisture content

10. GEOTECHNICAL EXPLORATION PROGRAM

- Unconfined compressive strength
- Unconsolidated-Undrained (U-U) triaxial compression

Laboratory testing of the overburden materials is necessary to evaluate soft ground tunneling methodologies, shaft excavation options, and temporary support methods. Laboratory testing on the core samples is required to determine the physical and mechanical properties of the bedrock. Various tests must be performed on multiple samples of each rock type identified along the project alignment to establish a range of values. The recommended laboratory tests should include:

- Bulk density and moisture content
- Unconfined compressive strength with elastic moduli determination
- Indirect (Brazilian) tensile strength
- Petrographic analyses
- Punch penetration index
- Cerchar abrasivity index
- Slake durability

Table 10.2 summarizes the sampling and testing schedule for the Phase 1 geotechnical exploration program.

Table 10.2
Phase 1 Sampling and Testing Schedule

Test/Sampling Method	Reference	Frequency
Standard Penetration Test	ASTM D1586	Every 2.5 to 5 feet in soil
Thin-Walled Tube	ASTM D1587	2 per boring [1]
Grain Size Analysis	ASTM D422 [2]	3 per boring
Atterberg Limits	ASTM D4318	1 per boring [1]
Consolidation	ASTM D2435	8 [1]
Rock Coring	As specified	Entire length of boring in rock
Water Pressure Packer Testing	As specified	Entire length of boring in rock
Moisture Content (Soil)	ASTM D2216	2 per boring
Sulfate	As specified [3]	1 per boring

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Table 10.2
Phase 1 Sampling and Testing Schedule

Test/Sampling Method	Reference	Frequency
Chloride	As specified [3]	1 per boring
Unconfined Compressive Strength (Soil)	ASTM D2166	8 [1]
U-U Triaxial Compression (Soil)	ASTM D2850	4
Unconfined Compressive Strength (Rock)	ASTM D2938	4 per boring
Rock Moduli in Uniaxial Comp.	ASTM D3148	1 per boring
Indirect Tensile (Brazilian) Strength	ASTM D3967	2 per boring
Cerchar Abrasivity	[4]	1 per boring
Bulk Density	[5]	2 per boring
Moisture Content (Rock)	ASTM D2216	2 per boring
Slake Durability	ASTM D4544	1 per boring
Punch-Penetration	[4]	1 per boring
Direct Shear (Rock)	ASTM D5607	10
Thin Section Analysis	[6]	1 per boring
Environmental Soil Samples [7]	As specified	1 per boring (21 borings)
Groundwater Samples [7]	As specified	selected piezometers

[1] Required only in cohesive soils, if encountered.
[2] Sample preparation by wet method of ASTM D2217, Procedure B.
[3] Samples collected from soil and groundwater collected from soil and rock.
[4] As performed by the Colorado School of Mines Excavation Engineering and Earth Mechanics Institute or equivalent.
[5] As described in Suggested Methods for Rock Characterization, Testing, and Monitoring (1981), International Society for Rock Mechanics Commission on Testing Methods, E. T. Brown, editor.
[6] As described in “Suggested Methods for Petrographic Description of Rocks,” International Society for Rock Mechanics, 1977.
[7] Soil and groundwater analyses include volatile and semi-volatile organics, polychlorinated bi-phenols, metals and pesticides. Groundwater analyses include methane and hydrogen sulfide.

It is recommended that a preliminary seepage model be developed to better define and understand the hydraulic interactions between the tunnel and the existing groundwater supply during construction and operation phases.

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10.2 PHASES 2 AND 3

Based on the data obtained from the Phase 1 geotechnical exploration program, Phase 2 should be developed and conducted during the detailed design to further define the existing conditions. Phase 3 geotechnical exploration programs are conducted during detailed design to fill any data gaps identified by Phase 2. To address any data gaps, identify hazards or conduct further hydrogeologic testing along the tunnel alignment, the scope of the Phase 2 and 3 geotechnical exploration programs may include, but is not limited to, the following:

- Additional borings
- Additional piezometer installations
- Soil and rock aquifer pump tests
- Geophysical surveys

The Phase 2 and 3 geotechnical exploration programs will likely concentrate on data collection for the soft ground and rock connection tunnels. In addition, if boulders are encountered during the Phase 1 geotechnical exploration program that restrict sampling efforts, alternative drilling and sampling techniques (e.g., using a Becker Hammer drill) may be considered during the Phase 2 and 3 geotechnical exploration programs.

10.3 GEOTECHNICAL DATA AND BASELINE REPORTING REQUIREMENTS

Upon completion of the Phase 1 geotechnical exploration program, a preliminary Geotechnical Data Report (GDR) should be prepared to document the findings. At a minimum, the GDR should include the following:

- Description of exploration program
- Description of region, site geology and hydrogeology
- Testing results
- Piezometric data

10. GEOTECHNICAL EXPLORATION PROGRAM

- Boring and well construction logs
- Recommendations for the Phase 2 and 3 geotechnical exploration programs

Upon completion of the Phase 2 and 3 geotechnical exploration programs, the preliminary GDR should be revised to include all additional geotechnical and hydrogeological project data from work performed under all tasks.

In addition to the GDR, a Geotechnical Baseline Report (GBR) should be prepared during the design to be included with the contract documents. The GBR is a contractural statement quantifying the baseline for the geotechnical conditions. The baseline statements in the GBR are not necessarily geotechnical facts. The Contractor should utilize the GBR to anticipate soil conditions that may be encountered during construction. Risks associated with conditions consistent with or less adverse than the baseline are allocated to the Contractor while those more adverse than the baseline are accepted by the Owner. Per the American Society of Civil Engineers (ASCE, 1997) guidance, baseline statements should include:

- Summary of geotechnical, hydrogeologic and construction conditions forming the design basis underground structures
- Estimated amounts and distribution of different materials along the alignment
- Description, strength, permeability, grain size and mineralogy of intact materials
- Description, strength and permeability of the ground mass as a whole
- Expected groundwater levels and conditions, and estimated pumping rates
- Anticipated behavior of the ground and the impact of groundwater, with regard to applicable methods of excavation and installation of ground support
- Construction impacts on adjacent facilities
- Potential or known faults and fault zones
- Other geotechnical and man-made sources of potential difficulty or hazard that could impact the construction progress, such as boulders, variations in top of rock, hazardous gas, contaminated ground and/or groundwater, and subsurface obstructions.